Bull. Fac. Agr., Saga Univ. (佐賀大農彙) No. 61 : 33~53 (1986)

# Comparative Analysis of the Potential Productivity of Pasture in Japan and New Zealand

Fumitake KUBOTA and Waichi AGATA*
(Laboratory of Crop Science and Faculty of Agriculture, Kyushu University*)
*Received May 7, 1986*

**Summary**

1. Potential productivities of orchardgrass (*Dactylis glomerata* L.) pasture at four sites, from Utsunomiya (36. 33 N. L.) to Sapporo (43. 03 N. L.), in Japan and 13 sites, from Auckland (36. 51 S. L.) to Invercargill (46. 25 S. L.), in New Zealand were predicted from the two climatic factors, air temperature and solar radiation. For the prediction employed was the production model formulated by authors.

2. The annual potential productivity in Japan ranged from 669 DW $m^{-2}$ $year^{-1}$ (Kushiro, 42. 59 N. L.) to 1,125 g DW $m^{-2}$ $year^{-1}$ (Utsunomiya). The range of New Zealand was from 759 g DW $m^{-2}$ $year^{-1}$ (Invercargill) to 1,682 g DW $m^{-2}$ $year^{-1}$ (Tauranga, 37. 40 S. L.).

3. In New Zealand the seasonal combination of air temperature and solar radiation was favorable to the $CO_2$ economic balance between photosynthesis and respiration in orchardgrass pasture, and the growth possible season in a year was long. The annual potential productivity in New Zealand was considerably higher as a whole than that of Japan.

4. In the northern region of Japan the seasonal change of potential productivity showed a mono-peaked curve with a peak in summer, while in the southern region it was double-peaked with a peak in spring and autumn. In New Zealand no large regional difference was found in the pattern of seasonal curve. The highest potential productivity was given in summer, in common, at all of the 13 sites.

5. The annual and seasonal potential productivities were compared with the actual yields of temperate type grasses observed in irrigated and non-irrigated pastures in New Zealand.

## Introduction

A large difference is found in climate between Japan and New Zealand. Japan is included in the Asian monsoon area, characterized by the large seasonal variation of climate. While New Zealand has a mild and stable climatic condition throughout the year.

We are interested in comparing potential productivities of pastures in both countries. "Potential Productivity" is also termed climatic productivity, which is recognized as the plant productivity determined by climatic factors only, on the assumption that the other environmental factors such as soil property, fertilizing level, disease and insect damage, and the like do not limit the plant growth. The potential productivity is considered as an idealized concept to explain the ecological background of plant production in a certain region.

The idea of potential productivity was stated as early as 1956 by K. J. Mitchel[27~29]. He predicted potential productivities of several pasture plants from both climatic factors, air temperature and solar radiation. After that J. N. Black (1962 and 1964)[9,10] obtained an estimate of potential productivity of subterranean clover (*Trifolium subterraneum* L.) from solar radiation only, and compared the estimated value with the real yield observed at Adelade in Australia. In these studies the potential productivities were obtained from the experimental data of pot-grown or small plot-grown plants[9,10,27~29].

Differently from them, we use here a mathematical method (production model) to know potential productivities. The production model has been formulated on the basis of the $CO_2$ balance between photosynthesis and respiration in plant population. At the first part in this paper, we give the outline of the production model formulating procedure. Then using the production model, the potential productivities of orchardgrass (*Dactylis glomerata* L.) pasture in Japan and New Zealand are predicted from both climatic factors, air temperature and solar radiation. Orchardgrass is one of main grass species grown in Japan. The regional difference in the potential productivity of orchardgrass pasture is discussed.

In New Zealand a large quantity of research has been conducted on the production of perennial ryegrass (*Lolium perenne* L.), a grass species dominantly grown in this country. Especially since 1974 J. E. Radcliffe and many other researchers have continued a series of investigations on the productivities of perennial ryegrass dominant pastures at various sites in New Zealand[6~8,12,13,17,30~38,40,41]. We compare these actual yields with the predicted potential productivities of orchardgrass pasture.

## Prediction of Potential Productivity by Production Model

The production model is consist of three equations, i. e. dry matter production (*DMP*) *equation*, crop growth rate (*CGR*) *equation* and $T_{c.\,max}$ *equation*. *DMP equation* is employed to simulate a dynamic change in the dry matter weight of pasture plants with re-growth after defoliation. Also the change of CGR is simulated by *CGR equation*. $T_{c.max}$ *equation* gives the day when the maximum CGR is presented.

Here we give a simple explanation for the formulation procedure and application method of the production model. The detailed discussion has been already done elsewhere[1~5,18~25].

## 1. Formulation of the production model

### (1) DMP equation

Primary production in plant is fundamentally determined by the $CO_2$ economic balance between photosynthesis and respiration in plant, expressed as an equation below.

$$W = (P - R) \times 0.61$$

where $W$ is production (dry matter weight), $P$ is the amount of photosynthesis ($CO_2$ weight) and $R$ is the amount of respiration ($CO_2$ weight) during a given period. A number, 0.61, is a conversion ratio from $CO_2$ weight into dry matter weight, that is $6CO_2 : C_6H_{10}O_5 = 1 : 0.61$ in molecular weight.

This equation is re-written as a differential equation (1).

$$\frac{dw}{dt} = p(t) - r(t)w \quad \cdots\cdots \quad (1)$$

where $w$ is plant weight (g DW $m^{-2}$), $t$ is the number of days after defoliation, $p(t)$ is the daily gain of dry matter (g DW $m^{-2}$ $day^{-1}$) by photosynthesis, $r(t)$ is respiration rate (g DW $g^{-1}$ $DW^{-1}$ $day^{-1}$). $r(t)w$ is the daily loss of dry matter (g DW $m^{-2}$ $day^{-1}$) by respiration, and $dw/dt$ is daily dry matter production weight (g DW $m^{-2}$ $day^{-1}$).

As leaf area of plants re-increases after defoliation, the photosynthetic rate in pasture increases linearly before reaching a plateau which appears at the late growth stage with a heavy mutual shading among leaves. The photosynthetic change in pasture with time is approximated by an equation of saturation curve (2).

$$p(t) = s(1 - e^{-at}) \quad \cdots\cdots \quad (2)$$

where $p(t)$ is the daily amount of photosynthesis (dry matter weight, g DW $m^{-2}$ $day^{-1}$), $t$ is the number of days after defoliation, and $s$ and $a$ are constants.

Respiratory rate, $r(t)$, in plant is assumed as a constant here because the variation of $r(t)$ with growth lies in a small range. Let $p(t) = s(1 - e^{-at})$ and $r(t) = r$, then $dw/dt$ is expressed as equation (3).

$$\frac{dw}{dt} = s(1 - e^{-at}) - rw \quad \cdots\cdots \quad (3)$$

By integrating equation (3) with respect to $t$, equation (4) is derived.

$$w = \frac{s}{r}(1 - e^{-rt}) + \frac{s}{r - a}(e^{-rt} - e^{-at}) + w_0 e^{-rt} \quad \cdots\cdots \quad (4)$$

where $w_0$ is the initial value of plant weight ($g\ m^{-2}$).

Equation (4) is termed *DMP equation* here.

### (2) CGR equation

Equation (5), or *CGR equation,* is derived by differentiating equation (4) with respect to $t$.

$$c = se^{-rt} + \frac{s}{r-a}(ae^{-at} - re^{-rt}) - rw_0 e^{-rt} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (5)$$

where $c$ is crop growth rate ($g\ m^{-2}\ day^{-1}$).

### (3) $T_{c.\ max}$ equation

After differentiating equation (5) with respect to $t$ ; let $c=0$, then equation (6) is obtained.

$$T_{c.\ max} = \frac{1}{a-r}\ln\frac{sa^2}{sar + r^2 w_0 (r-a)} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (6)$$

where $T_{c.\ max}$ is the day on which CGR gets to the maximum point.

The day having the maximum CGR ($CGR_{max}$) is predicted by equation (6). The value of $CGR_{max}$ is obtained by substituing the value of $T_{c.\ max}$ into the parameter $t$ in equation (5).

## 2. Application of the production model

### (1) Determination of parameter values

In order to determine parameter values in the production model, the rates of photosynthesis and respiration were periodically measured during the re-growth period of 54 day after defoliation in the orchardgrass pasture sufficiently fertilized and adequately irrigated[20]. The average air temperature and solar radiation during this period were 16 C and 360 cal $cm^{-2}\ day^{-1}$, respectively.

The change of daily photosynthetic amount, $p(t)$, is approximated by equation (2) (Fig. 1). As the values of parameter $s$ and $a$, 27. 72 and 0.126 are given, respectively. The value of parameter $r$ is 0.023[20]. The initial value of dry matter weight in plant, $w_0$, is 516.4[20].

By setting each parameter, $s=27.72$, $a=0.126$, $r=0.023$ and $w_0=516.4$, to *DMP equation* (4), the change of dry matter weight with time is simulated and compared with the observed values (Fig. 2). The simulated line of dry matter weight follows a s-shaped curve, dropping temporarily at the re-growth beginning stage, then rising curve-linearly. A satisfactory conformity is found between observed and simulated values.

Based on the parameter values presented above, parameter values of different climatic

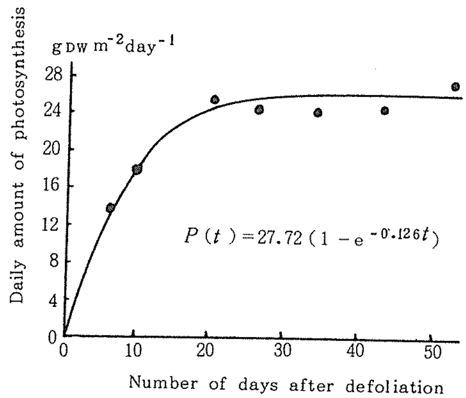


Fig. 1 Change in the daily amount of photosynthesis in orchardgrass pasture with growth after defoliation. The average air temperature and solar radiation during the experiment period were 16 C and 360 cal $cm^{-2}$ $day^{-1}$, respectively. (cited from F. Kubota *et al.*)[20]

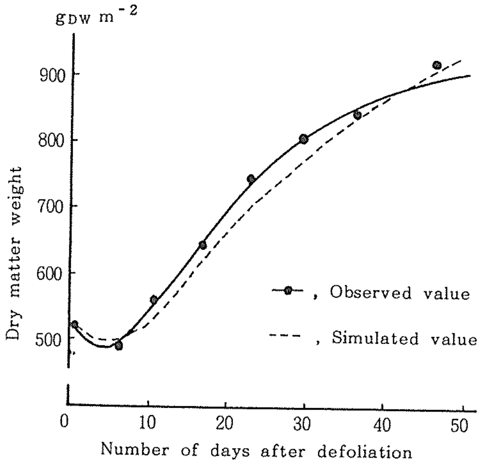


Fig. 2 Actually observed and simulated dry matter weights of orchardgrass pasture. *DMP equation* (4) was used for the simulation. (cited from F. Kubota *et al.*)[20]

conditions are determined. By which the pasture productions under the respective climatic conditions can be simulated[20, 23].

### (2) Changes in parameter values with air temperature and solar radiation.

Parameter $s$

i ) Change in parameter $s$ with solar radiation

The pattern of the photosynthetic change in pasture, $p(t)$, is determined by both parameter, $s$ and $a$, in equation (3). Of both parameters, parameter $s$ stands for the maximum value of $p(t)$, because $\underset{t\to\infty}{p(t)}$ equals $s$. At the combination of 360 cal $cm^{-2}$ $day^{-1}$ and 16 C, the value of parameter $s$ has been 27. 72, as described above. Provided that air temperature is 16 C constant, the value of parameter $s$ changes hyperbolicly with solar radiation, expressed as equation (7).

$$s = 27.72 \left(\frac{6.58 \cdot 10^{-3} I}{1+3.80 \cdot 10^{-3} I}\right) \quad \cdots\cdots\cdots\cdots\cdots \quad (7)$$

where $I$ is solar radiation (cal $cm^{-2}$ $day^{-1}$) and a mumber, 27.72, is the value of parameter $s$ given under the condition of 16 C and 360 cal $cm^{-2}$ $day^{-1}$.

ii ) Change in parameter $s$ with air temperature

Provided that solar radiation is 360 cal $cm^{-2}$ $day^{-1}$ constant, the value of parameter $s$ changes with air temperature only. The relationship between parameter $s$ and air temperature is presented as equation (8).

$$s = 27.72\ (5.81+1.37T+4.61\cdot 10^{-2}T^2-3.84\cdot 10^{-3}T^3 +5.16\cdot 10^{-5}T^4) \quad \cdots\cdots (8)$$

where $T$ is air temperature (C).

iii) Change in parameter $s$ with solar radiation and air temperature

In the case where both solar radiation and air temperature change, the value of parameter $s$ is given by equation (9) which has been derived by combining equation (7) and (8).

$$s = 27.72\ \left(\frac{6.58\cdot 10^{-3}I}{1+3.80\cdot 10^{-3}I}\right)\ (5.81+1.37T+4.61\cdot 10^{-2}T^2 -3.84\cdot 10^{-3}T^3+5.16\cdot 10^{-5}T^4) \quad \cdots\cdots (9)$$

Parameter $a$

Differentiate equation (3) with respect to $t$, then $p'(t)=sae^{-at}$ is obtained. Set $t=0$ then $p'(t)=s\ a$. The initial rising rate in the daily amount of photosynthesis in pasture, $p'(t)$, is determined by the product of $s$ and $a$.

Since parameter $s$ has been already fixed as described above, only a parameter $a$ is variable. The photosynthetic rate at the re-growth beginning stage increases in parallel with leaf area. Also the rate of leaf area increase at this stage exclusively depends on air temperature[23]. Accordingly, the value of parameter $a$ is determined by air temperature. Equation (10) shown below gives the values of parameter $a$ at different air temperatures.

$$\begin{aligned}
&5\mathrm{C}\leqq T\leqq 16\mathrm{C},\ a=0.126\ (0.09\cdot 10^{-2}T-0.4545)\ ;\\
&16\mathrm{C}\leqq T\leqq 20\mathrm{C},\ a=0.126\ (3.17\cdot 10^{-2}T-0.4921)\ ;\\
&20\mathrm{C}\leqq T\leqq 24\mathrm{C},\ a=0.126\ (-2.38\cdot 10^{-2}T+1.6032)\ ;\\
&24\mathrm{C}\leqq T\qquad\quad,\ a=0.126\ (-4.16\cdot 10^{-2}T+2.0381) \quad \cdots (10)
\end{aligned}$$

where $T$ is air temperature (C). A number, 0.126, is the value of parameter $a$ given under the condition of 16 C and 360 cal cm$^{-2}$ day$^{-1}$.

Parameter $r$ and $w_0$

Parameter $r$ represents the respiratory rate of plant. The rate of orchardgrass changes, at an index of $Q_{10}=1.65$, with air temperature. The relationship between parameter $r$ and air temperature is expressed as equation (11).

$$r = 0.023\ e^{0.05(T-16)} \quad \cdots\cdots (11)$$

where $T$ is air temperature (C) and a number, 0.023, is the value of parameter $r$ given at an air temperature of 16 C.

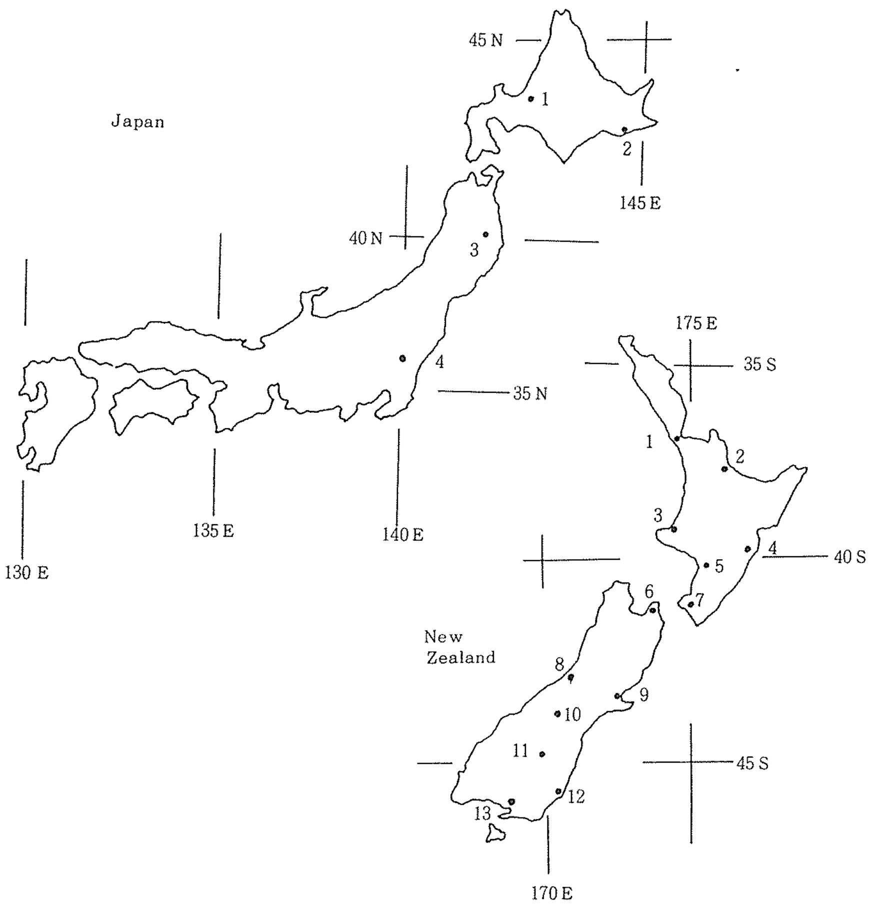


Fig. 3 Four sites in Japan and 13 sites in New Zealand selected for the prediction of potential productivities.
Japan: 1, Sapporo; 2, Kushiro; 3, Morioka; 4, Utsunomiya.
New Zealand: 1, Auckland; 2, Tauranga; 3, New Plymouth; 4, Napier; 5, Palmerston North; 6, Nelson; 7, Wellington; 8, Hokitika; 9, Christchurch; 10, Lake Tekapo; 11, Alexandra; 12, Dunedin; 13, Invercargill.

Parameter $w_0$, the initial value of dry matter weight in plant, is taken as a contant here because this parameter is variable with the previous growth condition before defoliation and independent of the current re-growth condition after defoliation. The observed weight, 516.4 g $m^{-2}$, is used here as the value of parameter $w_0$.

### (3) Calculation of monthly potential productivity (MP) and annual potential productivity (AP)

Dry matter weight in plant on the 30th day (a month) after defoliation is predicted by *DMP equation* (4), on the basis of the monthly average air temperature and solar radiation.

Equation (12) gives monthly dry matter production (g $m^{-2}$ $month^{-1}$).

$$\text{Monthly dry matter production} = w_{30} - w_0 \quad \cdots\cdots\cdots\cdots \quad (12)$$

where $w_0$ is the initial value of dry matter weight in plant ($w_0 = 516.4$ g m$^{-2}$), and $w_{30}$ is the dry matter weight (g m$^{-2}$) on the 30th day (a month) after defoliation.

Monthly potential productivity (**MP**) is expressed here as monthly average CGR (g m$^{-2}$ day$^{-1}$), given by equation (13).

$$\mathbf{MP} = \frac{w_{30} - w_0}{30} \quad \cdots\cdots\cdots\cdots \quad (13)$$

Annual potential productivity (**AP**) is the annual total value of monthly dry matter productions (g m$^{-2}$ year$^{-1}$).

Both **MP** and **AP** are predicted for four sites located in the northern cool area of Japan and 13 sites in New Zealand. These sites are pointed in Fig. 3.

### (4) Data of climatic factors

Climatic data of the four sites in Japan and 12 sites, excluding Palmerston North, in New Zealand were cited from the weather records, Climatic Table of Japan and World Survey of Climatorogy, respectively[43, 44]. The climatic data of Palmerston North were directly informed from DSIR of New Zealand. As sufficient data of solar radiation for

Table 1 Monthly changes in climatic factors, parameter values of the production model and potential productivities of orchardgrass pasture at Palmerston North in New Zealand.

| Month | | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. | Oct. | Mov. | Dec. | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sunshine duration (hr day$^{-1}$) | | 6.74 | 6.64 | 5.48 | 4.53 | 3.61 | 3.13 | 3.35 | 3.94 | 4.43 | 5.10 | 5.90 | 6.23 | |
| Solar rad. (cal cm$^{-2}$ day$^{-1}$) | | 468.7 | 416.2 | 310.9 | 219.2 | 146.7 | 119.2 | 134.6 | 183.6 | 254.9 | 322.5 | 415.2 | 462.1 | |
| Air temperature (C) | | 17.3 | 17.6 | 16.4 | 13.9 | 10.9 | 8.6 | 8.0 | 9.0 | 10.6 | 12.4 | 14.2 | 16.1 | |
| Precipitation (mm) | | 79 | 67 | 69 | 81 | 89 | 97 | 89 | 89 | 75 | 88 | 78 | 94 | 995 |
| Evaporation (mm) | | 168 | 143 | 115 | 66 | 40 | 24 | 25 | 42 | 65 | 98 | 129 | 154 | 1069 |
| Parameter | $s$ | 31.090 | 29.920 | 25.753 | 19.962 | 13.620 | 10.172 | 10.528 | 13.815 | 18.394 | 22.677 | 27.193 | 30.063 | |
| | $a$ | 0.1312 | 0.1324 | 0.1276 | 0.1019 | 0.0675 | 0.0412 | 0.0343 | 0.0458 | 0.0641 | 0.0847 | 0.1053 | 0.1264 | |
| | $r$ | 0.0246 | 0.0250 | 0.0235 | 0.0207 | 0.0178 | 0.0159 | 0.0154 | 0.0162 | 0.0176 | 0.0192 | 0.0210 | 0.0231 | |
| | $w_0$ | 516.4 | 516.4 | 516.4 | 516.4 | 516.4 | 516.4 | 516.4 | 516.4 | 516.4 | 516.4 | 516.4 | 516.4 | |
| $w_{30}$ (g m$^{-2}$) | | 773.0 | 749.6 | 692.7 | 602.7 | 494.6 | 430.6 | 426.3 | 476.8 | 558.2 | 639.8 | 721.6 | 769.3 | |
| Monthly D. M. production (g m$^{-2}$) | | 256.6 | 233.2 | 176.3 | 86.3 | −21.8 | −85.8 | −90.1 | −39.6 | 41.8 | 123.4 | 205.2 | 252.9 | 1138.3** |
| Monthly Ave.* CGR (g m$^{-2}$ day$^{-1}$) | | 8.55 | 7.77 | 5.87 | 2.87 | −0.73 | −2.86 | −3.01 | −1.32 | 1.39 | 4.11 | 6.84 | 8.43 | |

Solar rad., Solar radiation; $w_{30}$, Dry matter weight of plant on the 30th day after defoliation; Monthly D. M. production $= w_{30} - w_0$ ; Monthly Ave. CGR $= (w_{30} - w_0)/30$.
*, Monthly potential productivity (**MP**); **, Annual potential productivity (**AP**).

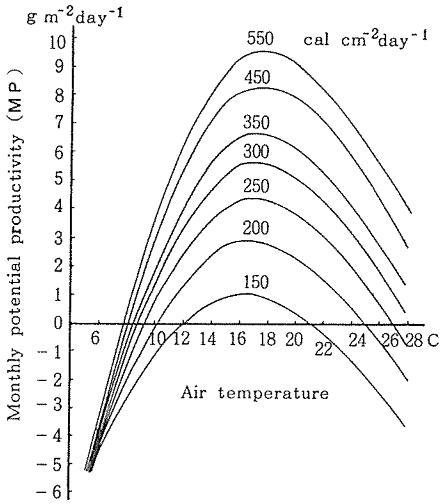


Fig. 4 Change in the monthly potential productivity (**MP**) of orchardgrass pasture with air temperature and solar radiation. **MP** is presented as monthly average CGR (g m$^{-2}$ day$^{-1}$).

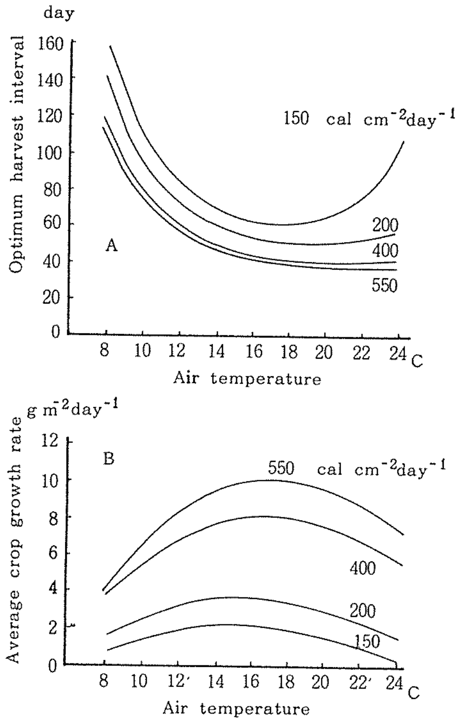


Fig. 5 Changes in the optimum harvest interval of orchardgrass pasture (A) and in the average crop growth rate during each optimum harvest interval (B) with air temperature and solar radiation.

these sites could not be obtained, we estimated the solar radiation from the sunshine duration.

Equation (14) gives the relationship between solar radiation and sunshine duration.

$$I = I_0\ (0.275 - 0.725n/N) \qquad \cdots\cdots\cdots\cdots (14)$$

where $I$ is solar radiation (cal cm$^{-2}$ day$^{-1}$), $I_0$ is the possible solar radiation (cal cm$^{-2}$ day$^{-1}$) of a completely clear day, $n$ is sunshine duration (hr day$^{-1}$) and $N$ is the possible duration of sunshine (hr day$^{-1}$).

## Results and Discussion

### 1. Potential productivity of orchardgrass pasture and climatic condition at Palmerston North in New Zealand

Palmerston North (40.23 S. L., 175.37 E. L.) is located at the central point in the main grass producing area in New Zealand. Air temperature, solar radiation, parameter values

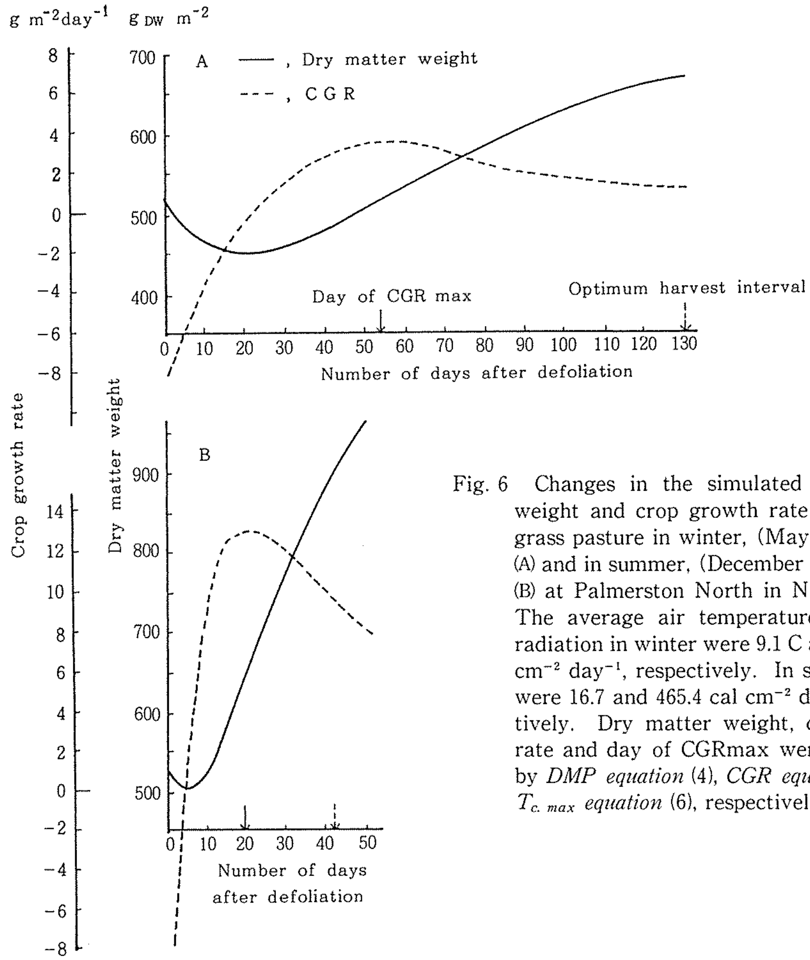


Fig. 6 Changes in the simulated dry matter weight and crop growth rate of orchardgrass pasture in winter, (May to August), (A) and in summer, (December to January), (B) at Palmerston North in New Zealand. The average air temperature and solar radiation in winter were 9.1 C and 146.0 cal cm$^{-2}$ day$^{-1}$, respectively. In summer they were 16.7 and 465.4 cal cm$^{-2}$ day$^{-1}$, respectively. Dry matter weight, crop growth rate and day of CGRmax were simulated by *DMP equation* (4), *CGR equation* (5) and $T_{c.\ max}$ *equation* (6), respectively.

of the production model, and monthly and annual potential productivity (**MP** and **AP**, respectively) at Palmerston North are listed (Table 1).

The **AP** of Palmerston North is 1, 138.3 g DW m$^{-2}$ year$^{-1}$, or 11, 383 kg DW ha$^{-1}$ year$^{-1}$, which is equivalent to around 60 t ha$^{-1}$ year$^{-1}$ in fresh yield. High values of **MP**, 8.43 and 8.55 g m$^{-2}$ day,$^{-1}$ are given in summer (December to January) during which monthly average air temperature is 16.1 to 17.3 C and monthly average solar radiation is around 460 cal cm$^{-2}$ day.$^{-1}$ While in winter (May to August), they are in the range of 8.0 to 10.9 C and 119.3 to 183.6 cal cm$^{-2}$ day,$^{-1}$ respectively, and **MP** shows negative values.

**MP** increases with rising solar radiation, and the optimum air temperature range is found around 16 to 20 C (Fig. 4).

The harvest interval during which the average CGR becomes highest is termed optimum harvest interval. This interval gets shorter exponentially with increasing air temperature and solar radiation. The shortest interval is given in the air temperature range from 18 to 20 C (Fig. 5).

Fig. 6 shows the simulated lines of dry matter weight and CGR in orchardgrass pasture

Table 2 Predicted values of crop growth rate and dry matter production weight of orchardgrass pasture during the optimum harvest interval in each season at Palmerston North in New Zealand.

| Season | Spring | Summer | | | Autumn | Winter | |
|---|---|---|---|---|---|---|---|
| Harvest interval (month) | Sep. 1 to Oct. 31 | Nov. 1 to Dec. 15 | Dec. 16 to Jan. 28 | Jan. 29 to Mar. 15 | Mar. 16 to May 15 | May 16 to Aug. 31 | Annual total |
| (days) | 61 | 45 | 45 | 45 | 61 | 108 | 365 |
| Ave. air temp. (C) | 11.5 | 14.8 | 16.9 | 17.2 | 13.8 | 8.9 | — |
| Ave. solar rad. (cal $cm^{-2}$ $day^{-1}$) | 291.2 | 430.8 | 466.5 | 381.1 | 224.0 | 145.9 | — |
| Ave. CGR (g $m^{-2}$ $day^{-1}$) | 4.81 | 8.27 | 9.01 | 7.74 | 4.22 | 1.04 | — |
| Production (g $m^{-2}$) | 293.2 | 372.4 | 405.6 | 348.3 | 257.9 | 113.0 | 1790.4 |

Ave. air temp., Average air temperature; Ave. solar rad., Average solar radiation; Ave. CGR, Average crop growth rate; Production, Dry matter production weight.

both in winter (May to August) and in summer (December to January) at Palmerston North. The optimum harvest interval is 130 days and the CGRmax appears on the 54th day after defoliation in winter. While 42 days and 20th day are given in summer, respectively. The average air temperature and solar radiation in winter are 9.1 C and 146.0 cal $cm^{-2}$ $day^{-1}$, respectively. Also they are 16.7 C and 465.4 cal $cm^{-2}$ $day^{-1}$ in summer, respectively.

Optimum harvest intervals in the other seasons at Palmerston North are known from the seasonal average air temperatures and solar radiations (Table 2). The optimum harvest interval and harvest frequency (pasture cutting times) in each season are predicted as follows; three-times harvests at 45 days intervals in summer, once harvest at 61 days interval each in spring and in autumn, and once harvest at 108 days interval in winter. Under this optimum harvesting system, the annual total harvest frequency is six times.

Of the potential productivities (average CGR) during these optimum harvest intervals, the highest value, 9.01 g $m^{-2}$ $day^{-1}$, is presented in mid summer (December 16th to January 28th) and the lowest value, 1.04 g $m^{-2}$ $day^{-1}$, is given in winter (May 16th to August 31st.) (Table 2). Under the optimum harvesting system, the annual production level rises to 1, 790.4 g $m^{-2}$ $year^{-1}$, which is about 60 % over the value of **AP**, 1,138.3 g $m^{-2}$ $year^{-1}$, predicted under the monthly harvesting system (Table 1). The production level of around 1,790 g $m^{-2}$ $year^{-1}$ may be regarded as an upper limit of the actual yield of orchardgrass pasture at Palmerston North.

B. J. Forde (1979)[16] stated that an annual yield of 10,560 kg DW $ha^{-1}$ $year^{-1}$ (1,056 g $m^{-2}$ $year^{-1}$) was obtained in the orchardgrass pasture irrigated, fertilized 500 kg N $ha^{-1}$ $year^{-1}$ and harvested five times in a year at Palmerston North. Also according to P. S. Evans (1978)[15], the annual yield of orchardgrass pasture was 12,140 kg DW $ha^{-1}$ $year^{-1}$ (1,214 g $m^{-2}$ $year^{-1}$) under the annual four-times harvesting system. These yields are 30 to 40 % lower than the production level of 1,790.4 g $m^{-2}$ $year^{-1}$ mentioned above. Even if pasture is controlled under the adequate soil moisture, sufficient fertilization and optimum harvesting system, the growth of pasture plants may be restricted by many other environmental factors.

Precipitation is one of the influential climatic factors on pasture production. At Palmerston North the annual total precipitation is 995 mm year$^{-1}$ and the seasonal variation of precipitation is small (Table 1). During the warm season (October to March) the evaporation exceeds the precipitation. Water deficit is often the most decisive factor limiting pasture production, since water stress is usually associated with periods of high air temperature and high solar radiation and hence high potential productivity.

J. E. Radcliffe (1976)[38] reported that water deficit periods for perennial ryegrass growth were relatively long, lasting 30 to 37 days in a year both at Flock House (40.16 S. L., 175.17 E. L.) and at Morton (40.05 S. L., 175.25 E. L.) close to Palmerston North. Also B. J. Forde *et al.* (1976)[16] compared the yields of orchardgrass pastures irrigated and non-irrigated in 1973 to 74 at Palmerston North. In this experiment the annual yield (10, 650 kg DW ha$^{-1}$ year$^{-1}$) from the irrigated pasture was not so large, only around 10 % higher than that (8,940 kg DW ha$^{-1}$ Year$^{-1}$) from the non-irrigated pasture. Orchardgrass is known as a species of higher tolerability against summer heat and drought than perennial ryegrass. However, if not irrigated, the growth of orchardgrass seems to be often seriously depressed by water deficits under the climatic condition at Palmerston North. The influence of precipitation on the pasture production in New Zealand is taken up again later.

Table 3 Climatic conditions and annual potential productivities (**AP**) of orchardgrass pasture at four sites in Japan and 13 sites in New Zealand

| Site | Latitude | Altitude (m) | Growing season | | | | | | Annual | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Months | Acc. rad. (×10$^2$) | Acc. temp. (×10) | AP (g m$^{-2}$) | AP (ratio) | CGR (g m$^{-2}$ day$^{-1}$) | Ave. temp. (C) | Range temp. (C) | Ave. rad. | Precip. (mm) |
| Sapporo | 43.03N | 18 | 6 | 705 | 294 | 1039 | 92 | 5.7 | 7.8 | 26.8 | 300 | 1140 |
| Kushiro | 42.59 | 32 | 5 | 495 | 210 | 669 | 59 | 4.4 | 5.5 | 24.5 | 297 | 1112 |
| Morioka | 39.42 | 155 | 7 | 829 | 347 | 1070 | 95 | 5.0 | 9.7 | 25.8 | 320 | 1279 |
| Utsunomiya | 36.33 | 120 | 8 | 864 | 426 | 1125 | <u>100</u> | 4.6 | 12.7 | 23.9 | 337 | 1464 |
| Auckland | 36.51S | 49 | 12 | 1154 | 553 | 1609 | 143 | 4.4 | 15.2 | 8.8 | 316 | 1242 |
| Tauranga | 37.40 | 4 | 12 | 1256 | 514 | 1682 | 150 | 4.6 | 14.1 | 9.7 | 345 | 1300 |
| New Plymouth | 39.04 | 49 | 12 | 1150 | 493 | 1467 | 130 | 4.0 | 13.5 | 8.0 | 315 | 1554 |
| Napier | 39.29 | 2 | 12 | 1202 | 507 | 1529 | 136 | 4.2 | 13.9 | 10.2 | 329 | 792 |
| Palmerston N. | 40.23 | 34 | 12 | 1052 | 471 | 1173 | 104 | 3.2 | 12.9 | 9.6 | 288 | 995 |
| Nelson | 41.17 | 2 | 9 | 1077 | 366 | 1437 | 128 | 5.3 | 11.8 | 10.5 | 341 | 912 |
| Wellington | 41.17 | 126 | 12 | 1126 | 451 | 1180 | 105 | 3.2 | 12.4 | 8.3 | 308 | 1250 |
| Hokitika | 42.43 | 4 | 9 | 889 | 337 | 1006 | 89 | 3.6 | 11.1 | 8.2 | 280 | 2764 |
| Christchurch | 43.32 | 7 | 9 | 926 | 359 | 1185 | 105 | 4.3 | 11.4 | 10.7 | 291 | 668 |
| Lake Tekapo | 44.00 | 683 | 7 | 853 | 271 | 1115 | 99 | 5.2 | 9.3 | 13.9 | 302 | 564 |
| Alexandra | 45.15 | 158 | 8 | 907 | 329 | 1241 | 110 | 5.1 | 10.4 | 14.4 | 292 | 335 |
| Dunedin | 45.55 | 2 | 9 | 837 | 339 | 941 | 84 | 3.4 | 11.0 | 8.7 | 260 | 787 |
| Invercargill | 46.25 | 0 | 8 | 801 | 279 | 759 | 67 | 3.1 | 9.7 | 8.5 | 257 | 1087 |

Growing season, Period during which the monthly average air temperature is above 8 C; Acc. rad., Accumulated solar radiation (cal cm$^{-2}$); Acc. temp., Accumulated air temperature (C); **AP**, Annual potential productivity; CGR, Average crop growth rate; Ave. Temp., Annual average air temperature; Range Temp., Annual range of monthly average air temperature; Ave. rad., Annual average solar radiation (cal cm$^{-2}$ day$^{-1}$); Precip., Annual total precipitation.

## 2. Variation in climatic condition and potential productivity of orchardgrass pasture in Japan and New Zealald

Climatic condition, growing season and **AP** of orchardgrass pasture at four sites located at 36.33 to 43.03 N. L. in Japan and 13 sites located at 36.51 to 46.25 S. L. in New Zealand are listed (Table 3). The growing season mentioned here is a period during which the monthly average air temperature is above 8 C, the lowest air temperature (monthly average) at Palmerston North (Table 1). In Japan the regional variation of annual average air temperatures lies in the range of 5.5 to 12.7 C and that of New Zealand is in the range of 9.3 to 15.2 C. Also the annual range of monthly average air temperatures in Japan is 23.9 to 26.8 C, which is about double that (8.2 to 14.4 C) in New Zealand. The growing season is five to eight months in Japan and seven to 12 months in New Zealand. The growing season in Japan is restricted by the large seasonal change of air temperature. For example, the annual average air temperature at Utsunomiya (36.33 N. L.) in Japan is a little less than 13 C, almost similar to that (12.9 C) of Palmcrston North. However the annual range of air temperature at Utsunomiya is 23.9 C, greatly larger than that (9.6 C) of Palmerston North. By which the growing season of Utsunomiya is limited short, eight months, which is two-thirds that (12 months) of Palmerston North.

Solar radiation decreases with rising of the latitudinal position in both countries (Table 3). The regional range is 297 to 337 cal $cm^{-2}$ $day^{-2}$ in Japan and 257 to 345 cal $cm^{-2}$ $day^{-1}$ in New Zealand. No large difference is found in it between both countries. While there is a large difference in the accumulated solar radiations during the growing seasons. The highest value in Japan is 864 $\times 10^2$ cal $cm^{-2}$ (Utsunomiya), while that in New Zealand is 1,256 $\times 10^2$ cal $cm^{-2}$ (Tauranga, 37.40 S. L.). The lowest value in Japan is 495 $\times 10^2$ cal $cm^{-2}$ (Kushiro, 46.25 N. L.), which is 40 % lower than that (801$\times 10^2$ cal $cm^{-2}$; Invercargill, 46.25 S. L.) of New Zealand.

**AP** in New Zealand is in the range of 1,682 g $m^{-2}$ $year^{-1}$ (Tauranga) to 759 g $m^{-2}$ $year^{-1}$ (Invercargill). While the range of Japan is 1,125 g $m^{-2}$ $year^{-1}$ (Utsunomiya) to 669 g $m^{-2}$ $year^{-1}$ (Kushiro). Relatively higher values are given to New Zealand (Table 3).

Of the 17 sites in Table 3, the two sites, Utsunomiya (36.33 N. L.) and Sapporo (43.03 N. L.), in Japan and the six sites, Auckland (36.51 S. L.), Palmerston North (40.23 S. L.), Hokitika (42.43 S. L.), Christchurch (43.32 S. L.), Alexandra (45.15 S. L.) and Invercargill (46.25 S. L.) in New Zealand have been chosen to set out their monthly changes in climatic factors (air temperature, solar radiation, and precipitation) and **MP**. Fig. 7 and 8 show the monthly changes in the climatic factors and **MP** at the 17 sites, respectively.

Utsunomiya is located in the area close to the southern bordering line for orchardgrass growth in Japan. The seasonal change of **MP** drows a double-peaked curve, in which higher and lower peaks appear in spring (May) and autumn (September to October), respectively (Fig. 8). In spring a favorable air temperature (16 C or a little higher) for orchardgrass growth and the annual highest solar radiation, 444 cal $cm^{-2}$ $day^{-1}$, are given (Fig. 7). In summer **MP** is seriously depressed, caused by a high air temperature (25 C on monthly average). As air temperature falls gradually toward autumn, **MP** begins to

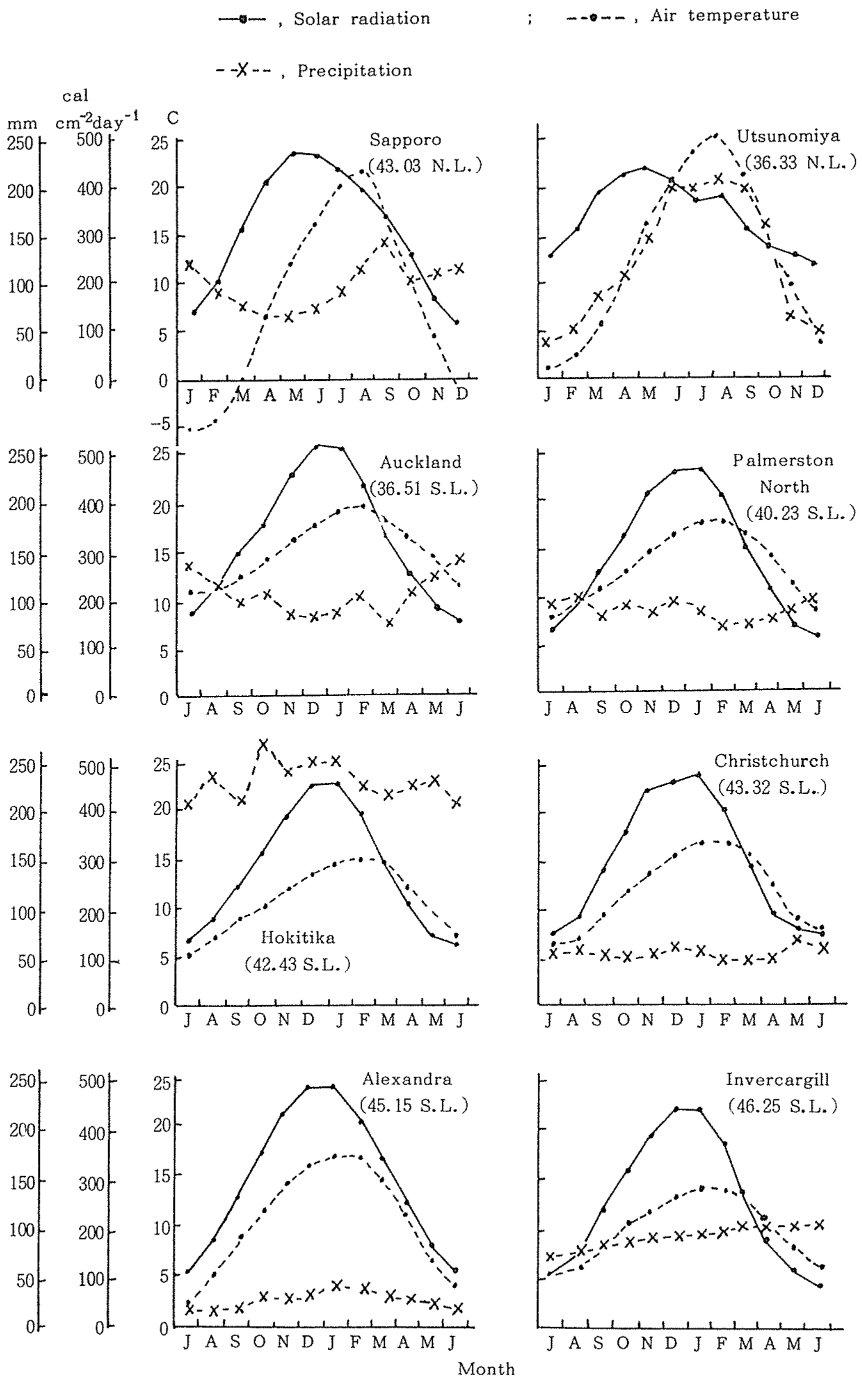


Fig. 7 Monthly changes in air temperature (C), solar radiation (cal cm$^{-2}$ day$^{-1}$) and precipitation (mm) at two sites in Japan and six sites in New Zealand.

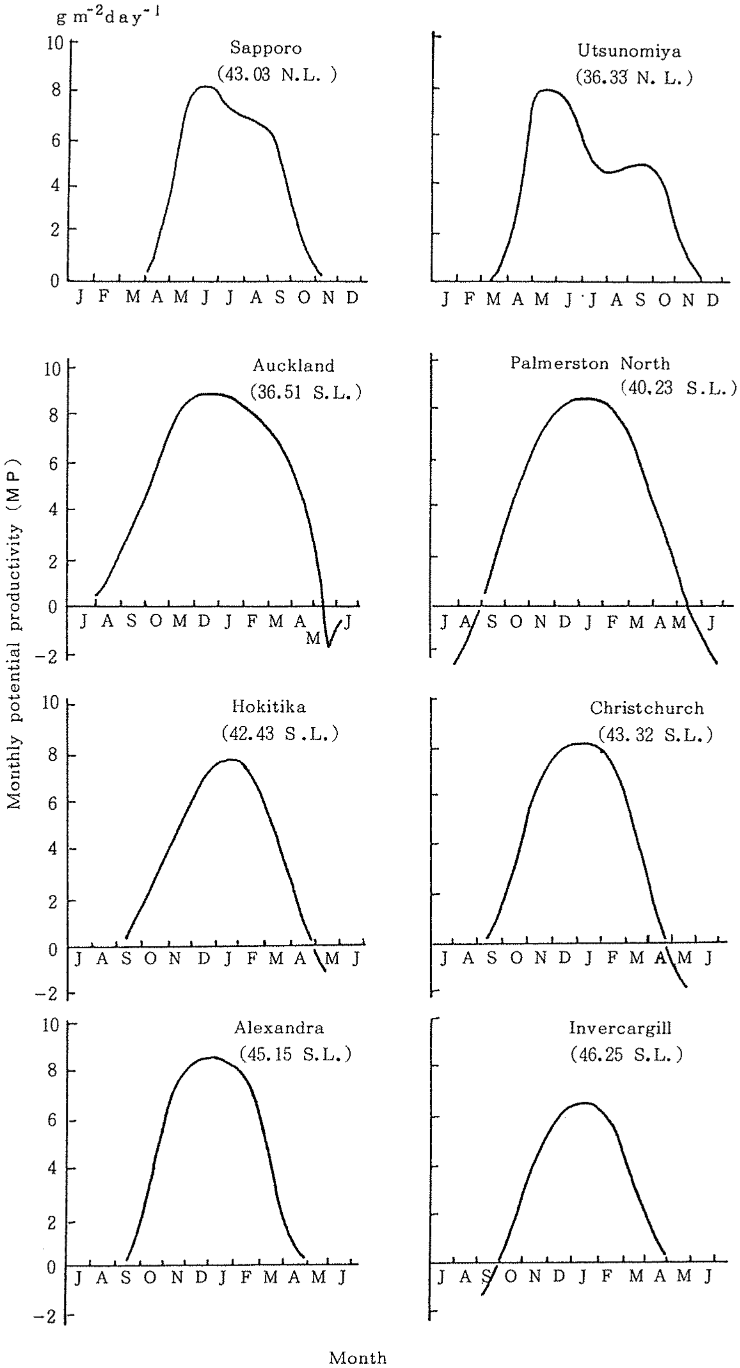


Fig. 8 Changes in the monthly potential productivity (**MP**) of orchardgrass pasture at two sites in Japan and six sites in New Zealand. **MP** is presented as monthly average CGR (g m$^{-2}$ day$^{-1}$).

re-increase. However, since the solar radiation decreases in parallel with decreasing air temperature, **MP** in autumn is lower than that of spring (Fig. 7 and 8).

Sapporo is located in the northernmost area in Japan and counted as the best site for orchardgrass production in this country. The average CGR during the growing season shows the highest value (5.7 g $m^{-2}$ $day^{-1}$) here among the four sites in Japan (Table 3).

The seasonal change of **MP** turns from double-peaked to mono-peaked curve with rising of the latitudinal position in Japan (Fig. 8). While in New Zealand such a trend is not found, and the seasonal change of **MP** presents a lenient mono-peaked curve in common.

At Auckland, a northern site in New Zealand, a favorable air temperature (15.9 to 19.6 C) for orchardgrass growth lasts for a long period (four months) from November to February, during which a high solar radiation, around 450 to 500 cal $cm^{-2}$ $day^{-1}$, is given (Fig. 7). In addition the monthly average air temperature is always above 10 C throughout the year, which makes possible a year-round production in orchardgrass pasture. Under this condition the **AP** of Auckland may reach a markedly high level, 1,609 g $m^{-2}$ $year^{-1}$, which is 43 % higher than that (1,125 g $m^{-2}$ $year^{-1}$, the highest level in Japan) of Utsunomiya (Table 3). For the other sites in New Zealand the growing season gets shorter and **AP** decreases with rising of the latitudinal postition (Table 3).

From the viewpoint of both climatic factors, air temperature and solar radiation, the growth condition of orchardgrass in Japan is, as described above, largely different from that of New Zealand. The air temperature changes greatly with season in Japan under the Asian monsoon climate. The annual range of air temperature (monthly average) is around 25 C, by which the growing season of orchardgrass is restricted short (Table 3). Especially at high latitudinal sites in Japan, the pasture productivity may be seriously reduced by the growth period shortening. While at lower latitudinal sites, the pasture production may be reduced by high air temperature in summer and unstabilized by the large seasonal variations of air temperature and solar radiation.

Contrary in New Zealand the seasonal change of air temperature is lenient and the growth season is long. In addition the seasonal combination of air temperature and solar radiation is favorable to the $CO_2$ economic balance between photosynthesis and respiration in orchardgrass pasture. Under this condition high and stable pasture production may be expected.

### 3. Actual and potential pasture productivity in New Zealand

The actual productivity of perennial ryegrass pasture and potential productivity of orchardgrass pasture are compared and discussed in relation to the climatic condition. Both grass species are classified as the temperate type and have a roughly similar growth reaction to climatic conditions.

Perennial ryegrass is the most popular grass species grown in New Zealand. A great deal of experimental data has been accumulated with this species in New Zealand. Especially years-long observations of the seasonal and annual yields have been carried out by J. E. Radcliffe and many other researchers, using the perennial ryegrass dominat pastures controlled under the fixed cultivation system[6~8, 12, 13, 17, 18~38, 40, 41].

According to the reports by J. E. Radcliffe *et al.*, the yields of perennial ryegrass pastures markedly rise in spring (October to November) and drop in summer (around December), in common, at many sites in New Zealand[6~8, 12, 13, 17, 30~38, 40, 41]. This pattern is much different from the mono-peaked seasonal curve which is shown in the potential productivity of orchardgrass pasture (Fig. 8).

Under the long day condition in spring to early summer, the stem elongation and ear emergence of temperate type grass species are promoted, and a large amount of substance moves from roots to shoots so that the aboveground weight (yielding part) of plant may markedly increase at this stage. However, when judged from the two climatic factors, air temperature and solar radiation, the summer condition in New Zealand is best for the $CO_2$ balance between photosynthesis and respiration in pasture, and the productivity (above + under-ground weight) of perennial ryegrass pasture should be highest in summer.

The mid summer drop of perennial ryegrass production in New Zealand is likely caused by drought. D. S. Rickard and P. D. Fitzgerald (1970)[39], and D. S. Rickard and J. E. Radcliffe (1976)[40] investigated the growth patterns in the irrigated and non-irrigated perennial ryegrass pastures set at a site close to Christchurch in Cantabury, a dry area in New Zealand. The seasonal growth curve presents a mono-peaked type with a peak in summer in the irrigated pasture. While in the non-irrigated pasture the summer growth is seriously depressed and the seasonal growth curve turns to the double-peaked type, with two peaks each appearing before and after summer. The annual yield (10,160 kg DW $ha^{-1}$ $year^{-1}$) in the irrigated pasture is almost duble that (5,870 kg DW $ha^{-1}$ $year^{-1}$) in the non-irrigated pasture[40]. Also similar results have been stated by J. R. Crush (1979)[14] and D. Scott and L. A. Maunsell (1981)[41]. If adequately irriagated, the summer productivity may rise to the annual highest level under the condition of favorable air temperature and high solar radiation.

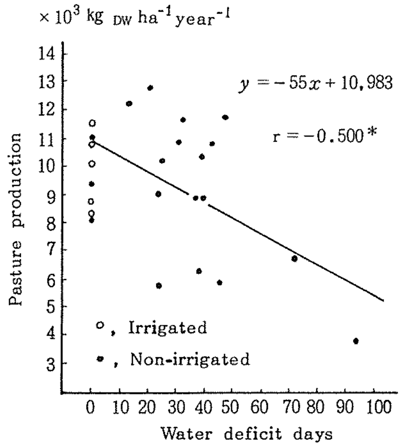


Fig. 9 Relationship between water deficit period and annual production observed in perennial ryegrass dominant pasture in New Zealand. (cited from the data published by J. E. Radcliffe and others[6~8, 12, 13, 17, 30~38, 40, 41])

J. D. Morton and D. J. Paterson (1982)[30] also stated that the highest productivity of perennial ryegrass pasture was found in summer (November to December) at a rainy site close to Hokitika where the annual total precipitation exceeds 2,000mm (Table 3). The seasonal growth curve at this site is almost similar to that (mono-peaked type) predicted for orchardgrass pasture at Hokitika (Fig. 8).

New Zealand is the archipelago stretching long from 34 S. L. to 48 S. L. in which air temperature and solar radiation decrease with rising of the latitudinal position. It is readily presumed from such a climatic gradient that the annual yield of perennial ryegrass pasture may have a similar decreasing trend with latitudinal rise. However such a trend is not found in the data published by J. E. Radcliffe *et al*[6~8, 12, 13, 17, 30~38, 40, 41]. For example, the annual dry matter yields in the perennial ryegrass dominant pastures are 12,010 to 14,610 kg DW $ha^{-1}$ $year^{-1}$ at Invercargill (46.25 S. L.)[33], the southernmost site, 10,920 to 8,100 kg DW $ha^{-1}$ $year^{-1}$ at middle latitudinal sites such as West Port (41.48 S. L.)[35] and Hokitika (42.43 S. L.)[30], and 10,220 to 12,760 kg DW $ha^{-1}$ $year^{-1}$ at northern sites such as Hamilton (37.50 S. L.)[8] and South Kaipara (36. 42 S. L.)[31].

At more than 25 sites in New Zealand water deficit periods for the perennial ryegrass dominant pastures have been observed by J. E. Radcliffe *et al*[6~8, 12, 13, 30~38, 40, 41]. Citing these data, the relationship between water deficit period and annual pasture yield is given in Fig. 9. The annual yield decreases with water deficit period, and their relationship is statistically significant. According to D. S Rickard and P. D. Fitzgerald (1970)[39], the major climatic limitation to pasture production in Cantabury is lack of moisture in summer and the seasonal dry matter production from a non-irrigated perennial ryegrass / clover pasture is strongly correlated with the number of days of drought. These facts suggest that precipitation may become a considerably influential factor on perennial ryegrass growth even under the wet oceanic climate of New Zealand.

J. P. Lambert (1973)[26] reported that the annual yields of orchardgrass pasture set at Kaikake (35.26 S. L.) close to Auckland were around 14,000 to 18,000 kg DW $ha^{-1}$ $year^{-1}$ (1, 400 to 1,800 g $m^{-2}$ $year^{-1}$) under the systems of harvesting at 28-and 42-day intervals . These yields are roughly equal to the **AP** (1,609 g $m^{-2}$ $year^{-1}$) of Auckland (Table 3). While the annual yields of perennial ryegrass pastures at Hamilton (37. 50 S. L.) and South Kaipara (36.42 S. L.) are, as mentioned above, around 10,000 to 13,000 kg DW $ha^{-1}$ $year^{-1}$ (1,000 to 1,300 g $m^{-2}$ $year^{-1}$), which is considerably lower than the orchardgrass yields above.

Orchardgrasss has a higher tolerability against summer heat and drought, so that its productivity may be superior to that of perennial ryegrass in the northern area in New Zealand. Also a relatively high yield, 17,160 kg DW $ha^{-1}$ $year^{-1}$ (1,716 g $m^{-2}$ $year^{-1}$), has been found in the temperate and tropical grasses mixed pasture at Dargaville (35.55 S. L.)[7]. The northern area of New Zealand seems to be the bordering zone between temperate and tropical grass species growth.

The volume of data on the yields of orchardgrass pastures is not enough in New Zealand, as compared with those of perennial ryegrass, so that it is impossible to drow the map of actual orchardgrass production in this country. However it may be predicted that precipitaion is less influential on the growth of orchardgrass, while air temperature and solar radiation come to play a more possitive role on the determination of orchardgrass pasture production under the climatic condition of New Zealand.

So far we have also predicted the potential productivities of orchardgrass pasture at various sites in Japan from air temperature and solar radiation, and compared them with actually observed yields. In many cases the actual yields and predicted values may present a good conformity. Excluding the extreme case, of many climatic factors both air temperature and solar radiation may be taken up as factors playing most influential roles for the determination of orchardgrass pasture production in Japan.

## Conclusion

Plant production is presented as an integrated result of various natural and artificial factors. Of many climatic factors, the three factors, air temperature, solar radiation and precipitation are measured in genral as most important determinants to plant production. However precipitation seems fundamentally different in its nature from air temperature and solar radiation. Precipitation deficits can be compensated by irrigation, though sometimes it is quite difficult, depending on circumstances, to perform. Conrary to this, air temperature and solar radiation are artificially uncontrollable factors in field.

Environmental factors may be classified into two types, primary determinant and secondary determinant to pasture production. Both climatic factors, air temperature and solar radiation, may be regarded as primary determinants, and the other natural and artificial factors including precipitation may be secondary determinants. The potential productivity of orchardgrass pasture obtained from air temperature and solar radiation may give a fundamental cocept to us in examining the actual pasture production.

In this paper, the discussion has been limited only to the two grass species, orchardgrass and perennial ryegrass, and also to the two countries, Japan and New Zealand. If the area of survey and analysis are extended to various regions with different climatic features, and more profound discussion is made on many other temperate and tropical pasture plants, it will be possible to deploy an ideal production system of pasture on the global level.

## Acknowledgement

Authors would like to express their appreciation to Dr. Cynthia M. Owen, Head Librarian of the Department of Scientific and Industrial Research (DSIR) in New Zealand, for giving them the valuable information of climate records of Palmerston North and the neighboring region.

## Literature

1. Agata, W., F. Kubota and E. Kamata. (1971). *J. Japan. Grassl. Sci.* **17**, 223—228.
2. ———, ——— and ———. (1972). *ibid.* **18**, 283—291.
3. ———, ——— and ———. (1973). *ibid.* **19**, 283—291.
4. ———, ——— and ———. (1977). *ibid.* **23**, 210—216.
5. ———, ——— and ———. (1978). *ibid.* **23**, 217—225.
6. Baars, J. A., J. E. Radcliffe and L. Brunswick. (1975). *N. Z. J. Exp. Agric.* **3**, 253—258.
7. Baars, J. A. (1976). *ibid.* **4**, 151—156.
8. ——— (1976). *ibid.* **4**, 157—161.
9. Black, J. N. (1962). *Aust. J. Agric. Res.* **14**, 20—38.

10. ——— (1964). *J. Appl. Ecol.* **1**, 3—18.
11. Brougham, R. W. (1959). *N. Z. J. Agric. Res.* **2**, 283—296.
12. Cossens, G. G. and J. E. Radcliffe. (1978). *N. Z. J. Exp. Agric.* **6**, 47—52.
13. Cossens, G. G. and D. W. Brash. (1981). *ibid.* **9**, 73—78.
14. Crush, J. R. (1979). *ibid.* **7**, 35—38.
15. Evans, P. S. (1978). *N. Z. J. Agric. Res.* **21**, 261—265.
16. Forde, B. J., C. R. Slack, P. G. Roughman and H. C. M. Whitehead. (1976). *ibid.* **19**, 135—142.
17. Greenwood, P. B. and G. W. Sheath. (1981). *N. Z. J. Exp. Agric.* **9**, 151—155.
18. Kubota, F., W. Agata and E. Kamata. (1971). *J. Japan. Grassl. sci.* **17**, 229—234.
19. ———, ——— and ———. (1972). *ibid.* **18**, 277—282.
20. ———, ——— and ———. (1972). *ibid.* **18**, 292—298.
21. ———, ——— and ———. (1973). *ibid.* **19**, 194—200.
22. ———, ——— and ———. (1973). *ibid.* **19**, 201—207.
23. ———, ——— and ———. (1973). *ibid.* **19**, 292—301.
24. ———, ——— and ———. (1973). *ibid.* **19**, 302—312.
25. Kubota, F. and W. Agata. (1974). *Res. Blut. Hokkaido Natl. Agric Exp. Stn.* **109**, 115—130.
26. Lambert, J. P., A. F. Boyd and W. Harris. (1973). *N. Z. J. Exp. Agric.* **1**, 15—22.
27. Mitchel, K. J. (1956). *Proc. Int. Grassl. Cong.* **7**, 58—68.
28. ——— (1956). *N. Z. J. Sci. & Techl.* **32**, 203—216.
29. ——— (1963). *Proc. N. Z. Inst. Agric. Sci.* **9**, 80—94.
30. Morton, J. D. and D. J. Paterson. (1982). *N. Z. J. Exp. Agric.* **10**, 245—252.
31. Piggot, G. H., J. A. Baars, G. L. B. Cumberland and E. N. Honore (1978). *ibid.* **6**, 43—46.
32. Radcliffe, J. E. (1974). *ibid.* **2**, 337—340.
33. ——— (1974). *ibid.* **2**, 341—348.
34. Radcliffe, J. E. and G. G. Cossens. (1974). *ibid.* **2**, 349—358.
35. Radcliffe, J. E. (1975). *ibid.* **3**, 239—246.
36. ——— (1975). *ibid.* **3**, 247—251.
37. ——— (1975). *ibid.* **3**, 259—265.
38. ——— (1976). *ibid.* **4**, 163—170.
39. Rickard, D. S. and P. D. Fitzgerald. (1970). *Proc. Int. Natl. Grassl. Cong.* **11**, 487—492.
40. Rickard, D. S. and J. E. Radcliffe. (1976). *N. Z. J. Exp. Agric.* **4**, 329—335.
41. Round-Turner, N. L., R. S. Scott and J. E. Radcliffe. (1976). *ibid.* **4**, 321—328.
42. Scott, D. and L. A. Maunsell. (1981). *ibid.* **9**, 279—290.
42. Climatic Table of Japan. (1971). Japan Meteorological Agency. Tokyo.
44. World Survey of Climatology. (1971). World Meteorological Organization. Geneva.

# 日本とニュージーランドにおける牧草地の潜在生産力の比較解析

窪田　文武・縣　和一
（作物学研究室・九州大学農学部栽培学研究室）
昭和61年５月７日　受理

## 摘　　　　要

１．日本の４地点およびニュージーランドの13地点における気温，日射量条件にともなうオーチャードグラス（*Dactylis glomerata* L.）草地の潜在生産力を推定した．推定には，著者らが創出した生産モデルを用いた．

２．オーチャードグラスの一年間の潜在生産力は，日本では，669 g DW $m^{-2}$ $year^{-1}$（釧路 42. 59 N. L.）から 1,125 g DW $m^{-2}$ $year^{-1}$（宇都宮 36. 33 N. L.）の範囲であった．ニュージーランドでは，759 g DW $m^{-2}$ $year^{-1}$（Invercargill 46. 25 S. L.）から 1,682 g DW $m^{-2}$ $year^{-1}$（Tauranga 37. 40 S. N.）の範囲であった．

３．ニュージーランドでは，気温と日射量の季節的組合わせ条件がオーチャードグラス草地の光合成と呼吸の炭酸ガス収支に好適であり，しかも日本に比較して生産可能期間が長い．ニュージーランド13地点の一年間の潜在生産力は，全体的に日本の４地点よりもかなり高い値を示した．

４．日本では，潜在生産力の季節変化の地域間差が大きく，北部では，季節生産曲線が単頂型を示し，南部では双頂型となった．ニュージーランドでは，このような明瞭な地域間差は，示されず，全13地点を通じて単頂型であり，夏期に最大値が示された．

５．ニュージーランドにおける年間および各季節の潜在生産力を灌漑及び非灌漑草地で実測した生産力と比較検討した．